Hydraulic properties of the Hemopump HP31: a study of the downstream pressure distribution

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***Abstract* – The Hemopump was commercialized as an useful tool for the left ventricle assistance. Bioengineers and clinicians showed great interest to develop applications and to analyze its hydraulic behaviour; in this work an application for axial pump in different conditions is presented. A study of the spatial pressure distribution generated by the impeller of the Hemopump is investigated in highly accurate steady-flow conditions.**

The experimental set up adopted for this study consists in a plexiglass test pipe (simulating an aortic conduit of 22-mm diameter) and allows the sampling of the pressure at the outlet of the pump in 16 points spaced ½ diameter each other. Keeping fixed the constant head at the inlet of the Hemopump and varying the constant head at its outlet, i. e. afterloads, in 11 step levels, it was possible to draw the characteristic flow curves versus delivered pressure for all the seven speed levels. A pressure range of about 35÷130 mmHg and a flow range of about –0.7÷3.7 l/min was experimented.

The results show that the flow delivered by the Hempopump is fully developed after 5 pressure taps (about 55 mm), with no further varying along the test chamber. These data could be used to optimize the setting up of clinical experimental procedures.

Keywords – Hemopump, spatial pressure distribution

I. Introduction

In recent years, the need has grown for mechanical circulatory support of the failing heart. Micro-axial blood pumps have been revealed as an useful tool either for short term or for chronic left ventricular assistance [1-7].

The Hemopump (Medtronic, Minneapolis, USA) is a device based on the principle of the screw pump: it furnishes, by conversion from electric energy, rotating energy to a high speed rotor [8]. The elevated speed rotation accelerates blood transferring it from the low pressure inlet to the high pressure outlet. The Hemopump is a device for left ventricular assistance having an axial pump, with an aspiration silicone cannula, connected by a flexible drive cable to an electromagnetic motor, this one being controlled by the Hemopump drive unit [7, 8]. The drive unit provides seven different speed rotation levels, trying to mantain at a costant value the pump rotation speed for each available setting controlling the motor current erogation in consequence of the changing pressure and flow working conditions. This current-controlled method does not allow to desume the pump flow from the selected rotation speed, with the consequence that the level of perfusion could be unpredictable, depending on preload and afterload conditions.

Our group used this axial pump to realize an extracorporeal circuit in the case of ewe's fetal cardiosurgery trials [9].

This device, in its normal use, is pushed through the aorta in the left ventricle and fixed in transvalvular position. Object of the present study is an in vitro test of the hydraulic performances of the HP31 in a cylindrical test chamber, to investigate the pressure distribution at diffent distances from the edge of the pump impeller. Fixing the constant head at the inlet of the Hemopump and varying the constant head at its outlet, it was possible to draw the characteristic flow curves versus delivered pressure for all the available pump rotating speed levels, to be used as a control grid in defining experimental procedures (cannulation, circuit length, etc.) such as in [9,10].

II. Materials & Methods

The experimental set up adopted for the investigation of the pressure distribution distal to the axial pump outlet is shown in Fig. 1. The hydraulic circuit is equipped with a plexiglas test pipe (22 mm diameter) with 16 equispaced taps (1/2 diameter length) for the pressure measurements. The latter were performed using water columns for each pressure tap (see Fig. 1) at the resolution of 0.05 cmH_2O. The Hemopump, mounting the aspiration cannula, was inserted co-axially within the test chamber, while two reservoirs were connected by plastic tubes.

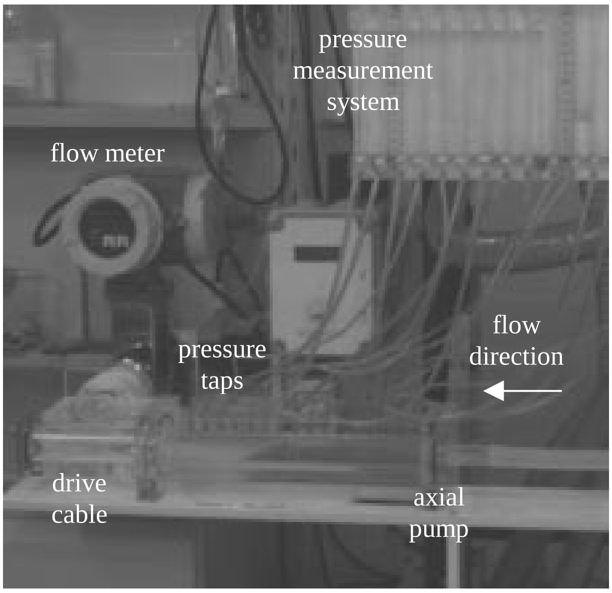

Fig 1. Experimental set up

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Abstract

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The hydrodynamic behaviour of the pump was investigated in an in vitro model filled with a 33% solution of water and glycerol, simulating blood viscosity.
The study was performed with respect to a feasible range of pressures delivered at pump's outlet [11, 12] using gravimetric heads, ranging from 35 to 130 mmHg; the test was performed investigating all the seven pump speed levels.
A centrifugal pump (Iwaki Co. Ltd) between reservoir 2 (output constant head) and 1 (input constant head) has been used, to supply constant head tanks.
Thus the hydraulic behaviour of the axial pump was investigated fixing the piezometric height of the reservoir 1 (input constant head), keeping at a constant piezometric height the reservoir 2 (output constant head), for all the seven pump speed levels; this configuration was repeated for eleven different piezometric heights of the reservoir 2, in elevation steps of 12.5 cm of water-glycerol solution (approximately 10 mmHg).
The above-described set-up allowed us to measure the difference between the pressure at the outlet of the pump (pressure value measured at the tap farthest from the pump's outlet) and the pressure proximal to the inlet of the aspiration cannula (calculated assuming a poiseuillian fluid motion in the adduction tube).
Pressure measurements have been done with a gravimetric system of very high precision, so that the standard deviations resulted of the same order of accuracy of the measurement system itself.
Flow measurements were performed with an electromagnetic flowmeter (Endress+Hauser), having 0.1% of accuracy in detecting fluid velocity.

III. Results

Figures. 2, 3, 4 show the pressure distributions along the test chamber (16 pressure taps) for three different speed levels (speed level 2, 4 and 7 respectively), for all the eleven investigated heights of the output constant head.

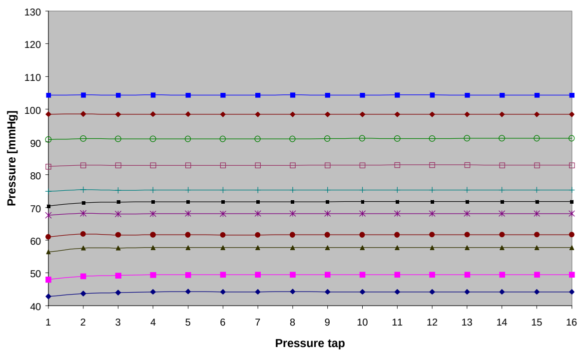

Fig 2. Pressure distributions along the test section at speed level 2 (from ♦=10 mmHg to ■=110 mmHg, step=10 mmHg)

It can be noticed how, for all the speed levels, the measured pressures showed an increasing trend as for the first 5, 6 pressure taps distal to the edge of the pump impeller. It is possible to underline how a difference in the piezometric height of the reservoir 2 (output constant head) sensibly modify the pressure delivered by the axial pump. This could be relevant when designing the length of an external circuit as well as of the cannulation.
Figure 5 shows the flow rate versus delivered pressure curves for all the eleven piezometric heights of the reservoir 2; it is possible to observe how, at all pump speed levels, a reduction of the afterload was associated to an increasing anterograde pump flow.

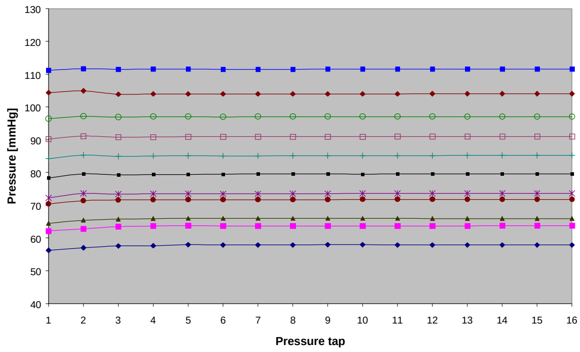

Fig 3. Pressure distributions along the test section at speed level 4 (from ♦=10 mmHg to ■=110 mmHg, step=10 mmHg)

Figure 5 also shows how retrograde flow was obtained at higher afterloads and lower speed levels (the three lower ones).
In Figure 6 the relationship is shown between the flow rates and the differences between the pressure at the outlet of the test section (measured at the tap farthest from the pump's outlet) and the pressure proximal to the inlet of the aspiration cannula.

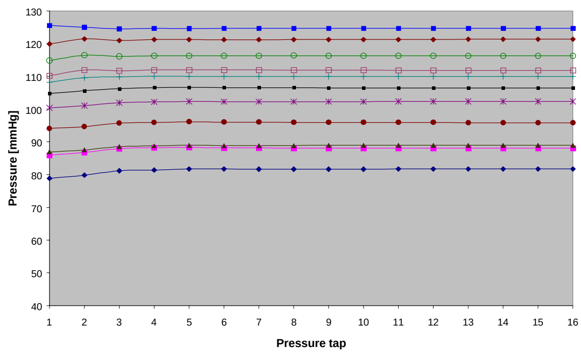

Fig 4. Pressure distributions along the test section at speed level 7 (from ♦=10 mmHg to ■ =110 mmHg, step=10 mmHg)

IV. Discussion

In this paper we measured the pressure spatial distribution distally to the edge of an HP31 impeller [6], in a cylindrical tube simulating an arterial site. This allowed us to quantify, under specific controlled conditions, the transitional length of the fluid motion, i. e., at which distance far from the edge of the axial pump impeller the flow can be considered fully developed; at the same time, pressure measurements can be considered stabilized.
We observed how, for all the investigated piezometric heights of the reservoir connected to the line of return of the experimental hydraulic circuit (output constant head), at a distance of about 55 mm away, distally to the edge of the

Hemopump impeller (i. e., the first five pressure taps, equivalent to a distance of abour three vessel diameters of the cylindrical test chamber), pressure reached an almost constant value, no further varying along the test chamber.

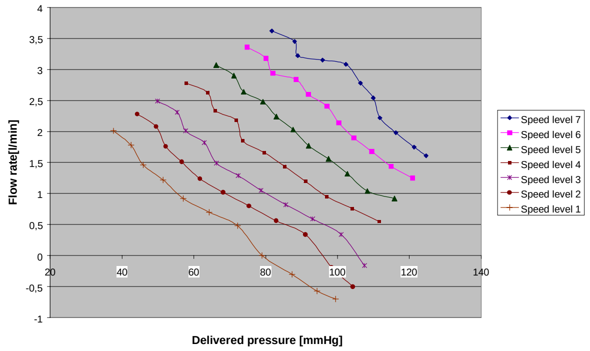

Fig 5. Flow rate versus delivered pressure curves relative to the considered eleven piezometric heights of the reservoir 2.

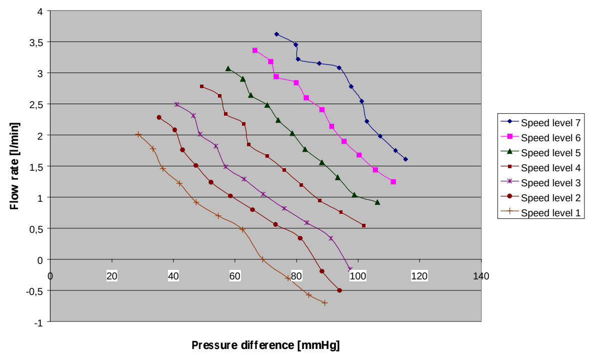

Fig 6. Flow rate versus pressure differences curves for all the eleven piezometric heights of the reservoir 2.

We observed how the axial pump is sensible to the afterload value: according to [11, 12], pump performance was significantly improved by afterload reduction. This means that in a beating heart, during the mechanical assistance, the blood flow provided by the pump is modulated by the arterial loading conditions, together with the ventricular contribution.. As a consequence, the current-controlled method governing the HP does not allow to desume the pump flow from the selected rotation speed, with the consequence that the level of perfusion remains not exactly predictable.
The level of indetermination in the flow rate delivered by the axial pump is an in vivo undesiderable feature, so that in vitro hydraulic characterizations of the HP31 could furnish useful estimations for clinical set up.
The pressure field at pump's outlet, for each afterload level and for each speed level, was investigated as a measure of the Hemopump's capability to convert kinetic energy into pressure; we demonstrated that this capability depends on the hydraulic characteristics of the circuit in which the pump is investigated. The data suggest that in vitro behaviours can be used to accurately set the experimental assistance and to correctly evaluate the results as in [9, 10].
The results presented in this paper also showed how for high afterload and low speed levels the fluid flow can even become negative, indicating a retrograde flow through the axial pump. We measured retrograde pump flow in correspondence of the first three pump speed levels,.suggesting that care must be paid to avoid this occurrence in vivo, in order to maintain the efficiency of the mechanical assistance.

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